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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DOR-533

THE GENERAL RESEARCH PROGRAM

15 JUNE 1967

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LINCOLN LABORATORY

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LEXINGTON MASSACHUSETTS

ABSTRACT

This report is a summary of Lincoln Laboratory's current program of General Research which is a source of new technology for projects of Lincoln Laboratory, the Department of Defense, and other federal agencies. The report covers research in Solid State, Data Systems, Radio Physics, and Communications.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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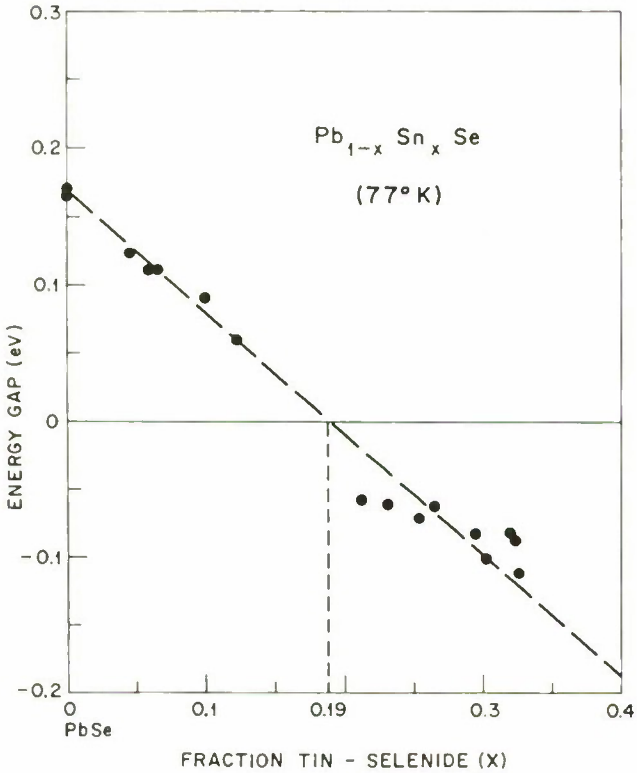
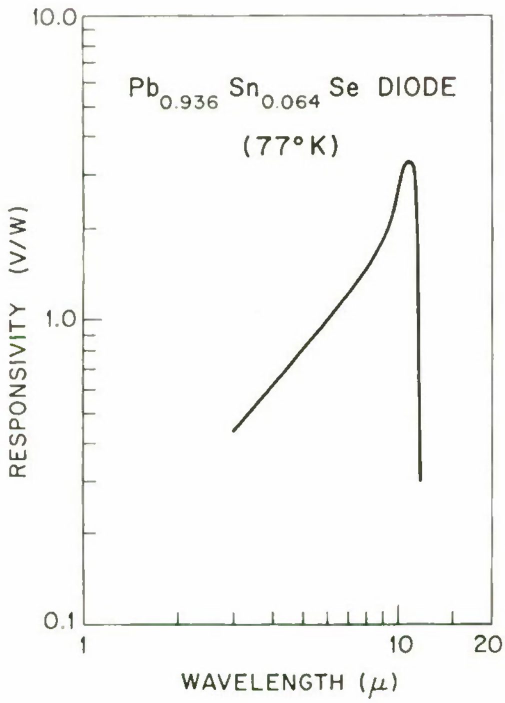
THE GENERAL RESEARCH PROGRAM

In 1951, at the joint request of the U.S. Army, Navy, and Air Force, Lincoln Laboratory was established as a research and development laboratory of the Massachusetts Institute of Technology. The mission of the Laboratory is to carry out a program of research and development pertinent to national defense with particular emphasis on advanced electronics.

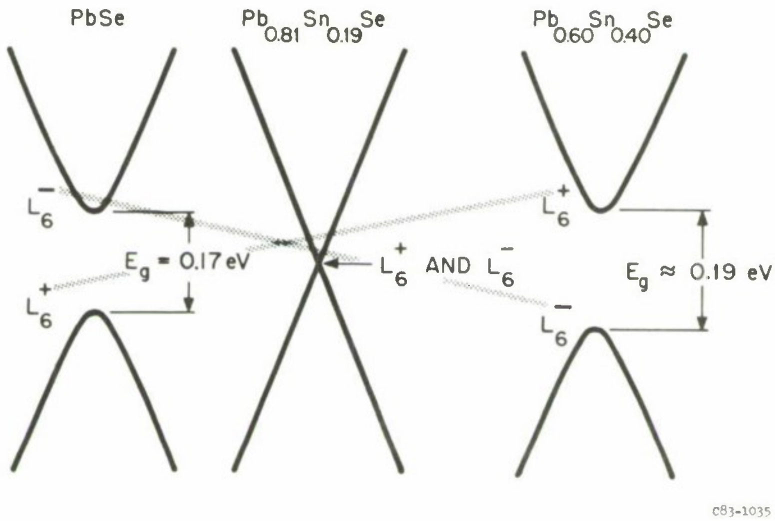
The Laboratory has played a major role in the origination and technical development of all three major U.S. air defense systems now in operational use: The DEW Line, the SAGE System, and the Ballistic Missile Early Warning System. With the formation of the MITRE Corporation in 1958, Lincoln Laboratory withdrew from manned bomber defense projects and has since engaged in new research projects addressed to three major military problems: understanding the electromagnetic engagement between ballistic missile re-entry systems and ballistic missile defense radars (Re-entry Technology), Space (satellite) Communications in a military environment, and the detection of underground nuclear explosions (Project Vela Uniform). The work done in direct pursuit of these goals is supported and supplemented by a program of General Research within which more fundamental research is carried on. The General Research program is sponsored by the U. S. Air Force.

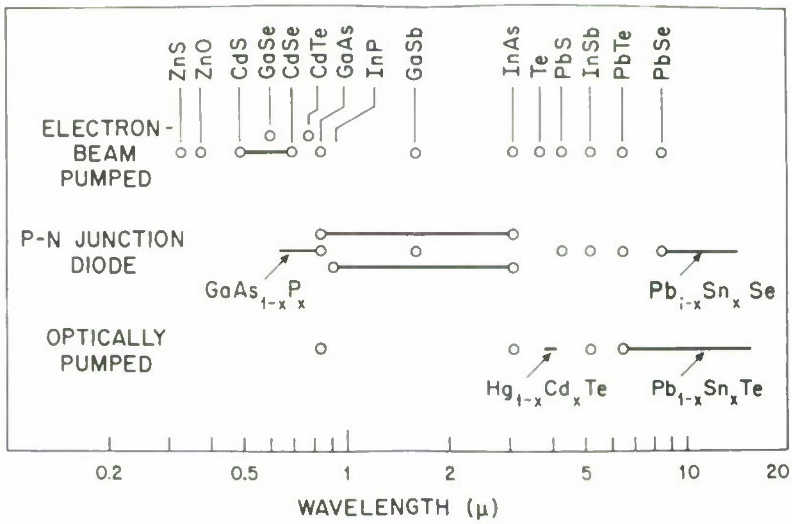
The work in Re-entry Technology includes three separate but complementary programs – PRESS, Radar Discrimination Technology, and Ballistic Missile Re-entry Systems – which contribute to the technology for defense against ballistic missiles and to the development of ballistic missile penetration aids. The PRESS and Radar Discrimination Technology programs are sponsored by the Advanced Research Projects Agency, and the Ballistic Missile Re-entry Systems work is sponsored by the U. S. Air Force acting as Department of Defense executive agent for all service sponsors. The work in Spaee Communications, under Air Force sponsorship, includes research on spaeecraft teehniques and on surface terminal techniques, leading to the development of both strategie and tactical military communication systems. The





Theoretical and experimental studies of electronic energy band structure show that the energy gap in lead-tin selenide (and lead-tin telluride) depends on the tin-to-lead ratio (above left), leading to interchange of valence and conduction bands (above right). Laser emission has been obtained from these alloys over a considerable range of infrared wavelengths, as shown at the right, by varying the composition. In addition, photovoltaic diode detectors fabricated from these alloys operate at useful infrared wavelengths (below left) up to liquid nitrogen temperature (77°K).





This drawing illustrates the large number of semiconductors from which laser emission has been obtained, indicating the pumping techniques employed and the output wavelengths, from zinc sulfide in the ultraviolet (upper left) to lead-tin telluride and selenide in the infrared (lower right). Many of these lasers originated in Lincoln's Solid State Research program.

beam pumping is exceedingly useful for materials that cannot be fabricated into p-n junctions, and for possible applications which involve scanning operations. With the increasing efficiencies that are being obtained, and with coverage of important spectral regions like the 8 – 14 μm atmospheric window, useful applications can be contemplated in communications, imaging displays, and other areas of coherent radiation utilization. Lead-tin-telluride and lead-tin-selenide alloys are presently being investigated for long-wavelength infrared emitters as well as sensitive photovoltaic infrared detectors. These detectors in their first stages of development show great promise; operating at liquid nitrogen temperature, they already cover the infrared atmospheric window and beyond almost as well as the HgCdTe detectors presently in field use. In another infrared region of considerable interest, from 2 – 5 μm, infrared photovoltaic response with quantum efficiencies up to 25% has been observed in a large-area InSb metal-oxide-semiconductor structure. The simplicity of the structure makes it particularly attractive as a method of making large arrays of detectors for infrared image converters.

2. Wide Bandgap II-VI Semiconductor Lasers

Investigation of some of the II-VI semiconductor compounds has proved to be quite fruitful in obtaining efficient visible and ultraviolet lasers. Electron beam excitation of CdS, CdSe and mixed crystals of CdS_xSe_{1-x} has produced laser oscillations at several wavelengths in the visible from 0.69 μm to 0.49 μm, with up to 350 watts peak output power and overall efficiency up to 25% at temperatures as high as 110°K. The shortest wavelength solid state laser that has been made to date is a relatively efficient (6.5%) electron-beam-pumped semiconductor laser of ZnS operating at 3245 Å with several watts peak power output. A more systematic investigation of the wide bandgap II-VI semiconductors is now under way. Initially the effort will be concentrated on CdS and the $ZnTe_xSe_{1-x}$ alloy system.

New fabrication techniques are being explored in order to improve the performance of existing lasers and to produce luminescent diodes and diode lasers in new materials. In particular, the possibility of using ion implantation to make p-n junction lasers from wide bandgap II-VI semiconductors is

being investigated, with the eventual objective of producing a visible CW diode laser at room temperature. At present, a 400 keV Van de Graaf positive ion accelerator is being used to study the implantation of phosphorus ions in CdS and CdTe; earlier results with this system showed that n-type regions could be produced in bulk p-type Ge by phosphorus implantation.

3. CO_2 Laser Radar

Because of the recent rapid development of CO_2 lasers, the possibility of applying optical radars to the measurement of ballistic missile re-entry phenomena has reached the stage where initial system tests seem highly desirable. An essential intermediate step is the construction and test of a CO_2 laser radar tracker capable of acquiring and tracking satellites. A precision microwave radar is necessary for acquisition of targets. Using CO_2 lasers at 10.6 μm wavelength, optical radar studies are being carried out on short-range targets such as aircraft. Satellite radar measurements have already been performed with a high-power ruby laser system in conjunction with the Millstone microwave tracking radar. Detectors, modulators, and other necessary components are under development for the CO_2 laser radar program. Low-power stable master oscillators and an optical heterodyne receiver have already been constructed.

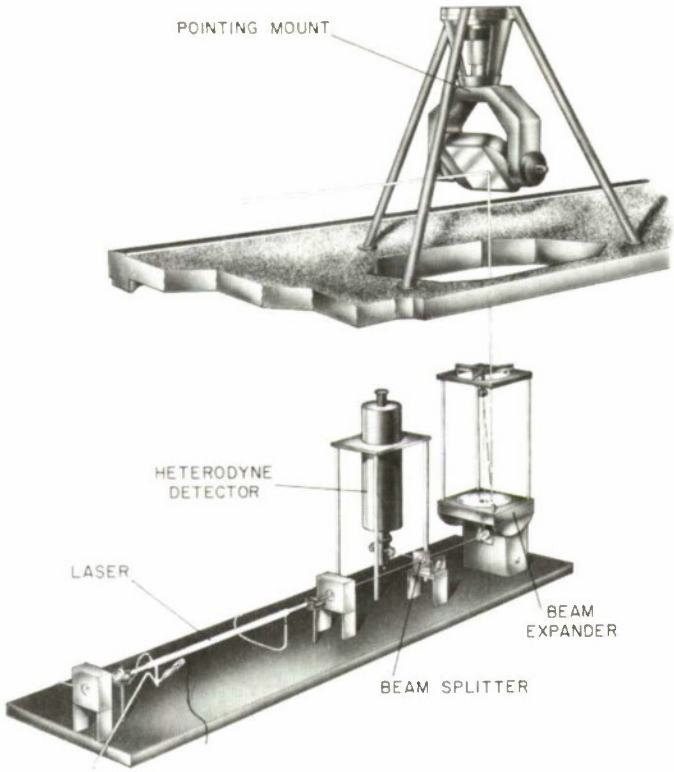
4. Thermal Detection and Tracking

Satellite tracking by means of thermal emission in the 8 – 12 μm atmospheric window is also being carried out in order to determine absolute tracking capabilities as well as atmospheric limitations. Target radiation characteristics should be correlated with such satellite characteristics as tumbling rate, solar exposure history, and configuration. These experiments utilize an extremely sensitive copper-doped germanium photodetector developed for the purpose.

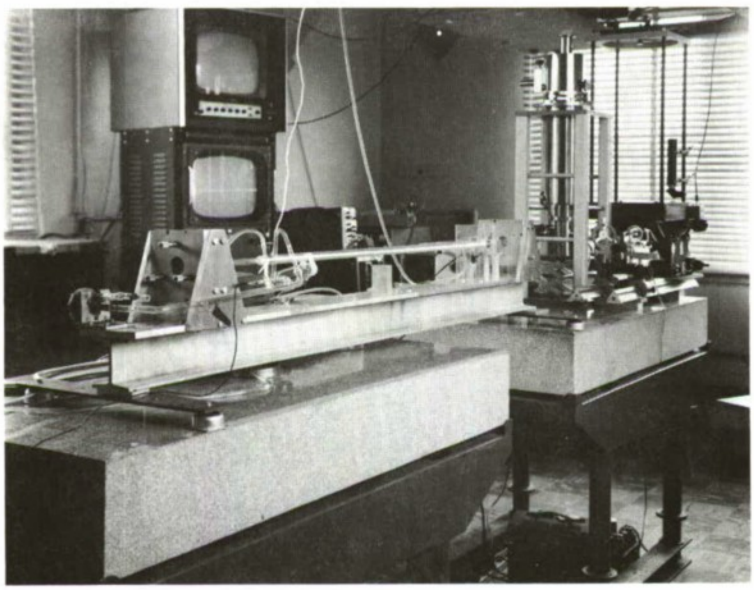
C. BASIC RESEARCH

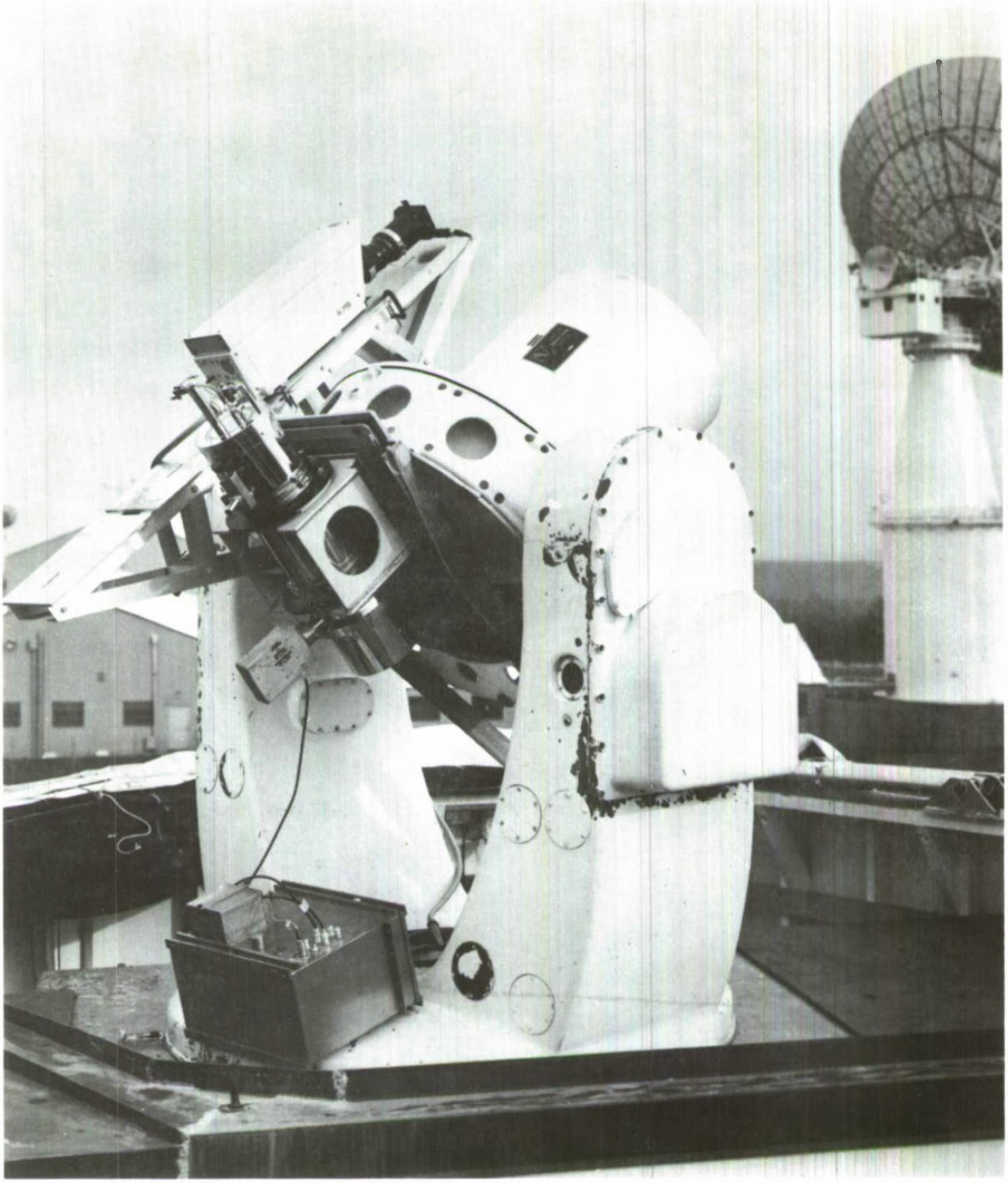
1. Magneto-optic Spectroscopy

Experimental and theoretical investigations are conducted in the area of electronic band structure in metals, semi-metals, and semiconductors. The



Infrared carbon dioxide CW Doppler laser radar system with sensitive heterodyne detector operates at 10.6 μm wavelength.





8-12 μm infrared thermal satellite tracking system with helium-cooled copper-doped-germanium detector at the Millstone Hill Field Station.

principal technique is magnetospectroscopy, utilizing electromagnetic radiation from the microwave to the "vacuum" ultraviolet spectral region. Several new detection methods involving sample modulation by electric fields (electroreflectance), strain (magneto-piezoreflectance), or temperature (thermal modulation) have recently been developed. These methods, coupled with the use of lasers as spectroscopic sources, allow the investigation of energy levels in materials with much higher resolution than was previously possible. The behavior of polarons in a magnetic field has been analyzed theoretically and is being studied in InSb in interband and intraband magneto-absorption measurements. The Fourier expansion technique for energy bands has been successfully applied to the description of a number of solids, including Ge, Si, Al, and graphite.

When appropriate, the well-established tool of microwave magnetospectroscopy in solids rather than optical magnetospectroscopy is employed, as, for example, in magnetoplasma cyclotron absorption in PbSe or helicon wave propagation in PbTe.

2. Magnetic Structure and Resonance

New magnetic materials are explored through the use of neutron diffraction, susceptibility measurements and magnetic resonance. Some time ago the insulating ferromagnetic spinels $CdCrSe_4$ and $CdCrS_4$ were discovered at Lincoln Laboratory as well as at the Radio Corporation of America, and their properties are currently being examined by nuclear magnetic resonance, paramagnetic resonance, and susceptibility behavior as a function of temperature. On the theoretical side, the classical Heisenberg model of ferromagnetism has been re-examined. By means of a classical rather than a quantum mechanical model, high temperature expansions of magnetic susceptibility have been shown to be enormously simplified. Other theoretical and experimental studies, including synthesis of specific materials and their x-ray characterization, involve the fundamental description of magnetic materials in terms of a localized electron spin vs a band model.

3. Quantum Electronics

This subject covers primarily two areas: laser scattering from collective excitation, such as phonons, polarons, plasmons and magnons; and nonlinear optics, which is concerned with the behavior of matter subject to intense optical fields such as those produced by high-power lasers.

In scattering experiments using relatively low-power CW lasers such as He-Ne and Nd^{3+}:YAG, the interaction of plasmons with phonons has been observed in the Raman spectrum of GaAs. Raman and Brillouin spectra are being studied in GaP, GaS, GaSe, Se, and other materials for a determination of their structures, symmetries and elastic forces. The success of such experiments depends a great deal on the development of sensitive instrumental techniques, such as photoelectric counting of individual quanta of light and the use of double monochromators and high-resolution Fabry-Perot etalons.

High-power lasers are being used to study the stimulated emission of radiation through the Raman and Brillouin effects in a number of solids and liquids. Some of the results require explanations in terms of a nonlinear (power-dependent) index of refraction and self-focusing of intense optical beams, a phenomenon which is also being analyzed extensively on the basis of theoretical models.

An application of the study of quantum electronic processes to other fields has been the detailed development of a maser amplifier model, in collaboration with Lincoln Laboratory radio astronomers, to account for the anomalous 18 cm interstellar OH emission.

4. Microwave Acoustic Interactions

In addition to electromagnetic waves, acoustic waves provide an important tool in the investigation of matter and exploration of potentially useful processes. Coherent ultrasonic waves have been generated with frequencies corresponding to the millimeter region of the electromagnetic spectrum. Techniques developed for depositing thin CdS films for microwave ultrasonic generation up to 9 GHz in nonpiezoelectric crystals and semiconductors have made possible the study of new microwave-acoustic interactions, as, for example, the

first direct measurement of the piezoelectric constant and deformation potential in InSb. The CdS thin film transducers will also probably offer the flexibility needed to investigate relatively efficient, broad-band transducers for VHF applications.

DATA SYSTEMS RESEARCH

A. INTRODUCTION

The long-term objective of the Laboratory's research on data systems is to increase significantly the usefulness of the digital computer as a tool for analysis and synthesis of large, complex physical systems and for analysis of the large amounts of data associated with such systems. Toward this end, the Data Systems research program supports the development of more economical and more powerful data-processing equipment, and of more effective ways of using such equipment. The many, varied substantive computational problems which originate in other Laboratory technical programs provide valuable opportunities for experimental evaluation of new data systems technology in a realistic context. The research program centers around two major computational facilities: TX-2 and the IBM 360/67.

TX-2 is a large machine designed and built at Lincoln. It serves as a test bed for new hardware developments: the first magnetic film memory, for example, was operated – and still operates – in TX-2, as does the first hardware implementation of a double-level, paged and segmented addressing system. In addition, TX-2 has an unusually flexible input-output system that makes it a unique facility for the experimental investigation of the interactions among software, hardware, and operating procedures in the development of new data-processing concepts.

The IBM 360/67 serves as the new central computing facility for the Laboratory. It was designed to meet Lincoln specifications which were, in turn, based on results and experience gained from the Data Systems Research program, including the design and operation of TX-2. The 360/67 will make possible on-line support of large-scale experimental and engineering work by a fully time-shared computer. It will supply the capability to perform conventional programming on-line, and it will also permit on-line data reduction, data analysis and editing, and direct, real-time interaction with various experimental measuring equipments. This mode of operation and many of these applications are new; hence, a substantial part of the Data Systems

Lincoln Laboratory Computation Center, showing IBM 360/67 computer with two central processing units (upper left) and three core memory modules, and (upper right) a 360/40 used in support of the 360/67. A number of individual time-sharing consoles are in regular use at remote locations in the Laboratory.

Research effort will continue to be devoted to the operation and evolution of the 360/67 system.

The principal tasks which make up the current research program may be grouped under the headings of on-line data processing and man-machine communication. The latter includes a substantial effort on computer graphics, with emphasis on graphical inputs as well as display.

B. ON-LINE DATA PROCESSING

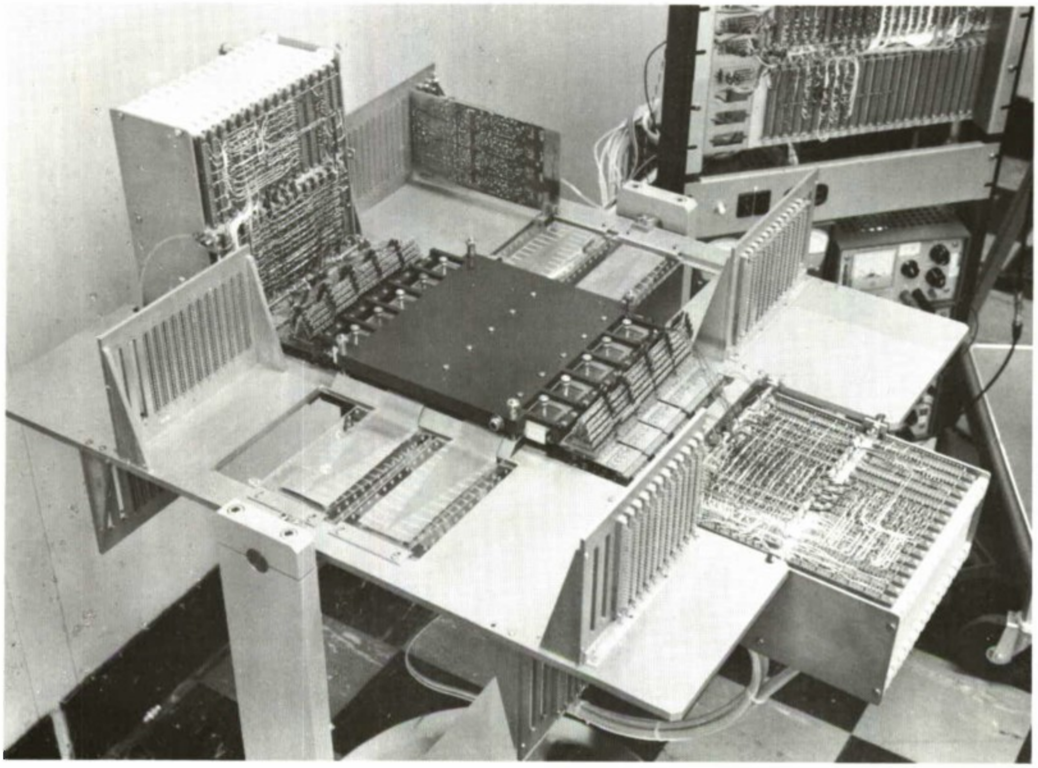
1. Computer Hardware

There is a strong interaction between hardware and software development, particularly for on-line or direct-access systems. Time-sharing, for example, can be implemented on conventional machines by programming alone, but, for reasons of economy and efficiency, it is necessary to make changes in the hardware (direct memory access, dynamic address translation, high-speed swapping drums, etc.). Accordingly, a substantial portion of the Data Systems research program is directed at innovation in machine design.

Computer memories have always been the principal limiting factor in terms of system cost and speed. For this reason, the Data Systems research program is pursuing the development of very-high-speed magnetic-film stores, with contributory studies in magnetic-film physics and other areas of the supporting technology. As a consequence of major advances that have been made in the past few years, the Laboratory has currently under development an experimental prototype memory that may lead the way to large (10^7 bit), high-speed (1 μsec) internal memories at a cost decrease of more than an order of magnitude.

2. Basic Research on Components

The hardware effort is supported by a program of fundamental research, in which a subject of primary concern is a more complete understanding of the switching process in magnetic films, to serve as a basis for future engineering exploitation of this medium. Optical readout of magnetically switched films is being investigated, since recent theoretical analysis suggests that,



Experimental prototype magnetic-film memory serves as a vehicle to define and solve problems in the design and fabrication of large-capacity, high-density, fast and economical computer storage. This memory has a capacity of 1 million bits, a packing density of 12,500 bits per square inch, and parallel access to a block of ten 32-bit words in less than 1 microsecond.

with the appropriate film and dielectric construction, optical readout might be utilized in large, fast, random-access memories. Further theoretical and experimental investigation of the physics of this technique is being pursued.

3. Memory Organization

The reduction and analysis of large quantities of experimental data recorded as part of the Laboratory's work in other projects is a major, continuing problem. Sheer volume requires the employment of a large computer, but something more than processing capacity is needed. Ideally, the analyst should be able to retrieve selected data easily, for display and inspection, and he should be able to intervene in the data reduction process. It should be possible to do this on-line, with text as well as numbers, with procedures as well as data, and without an ad hoc programming effort for each particular analysis or data set.

The "virtual memory" system, as implemented on TX-2 and the IBM 360/67, is a step toward meeting these needs. The user is provided with an address space very much larger than the physical memory in which the program is executed. Hardware-implemented address translation and an appropriate operating system permit programs and data to be organized within the virtual memory without significant inefficiency of execution. Research is now directed at exploitation of this capability, to permit the user to define, search, modify, and cross-associate large data files to suit his special needs. The files thus defined and retrieved would be in a form that could be operated on by various computational routines or by a general editing program that is also under development.

4. Netting of Computers

There is a factor similar to "critical mass" associated with any general-purpose, direct-access computing facility. A central machine must be large to handle efficiently the requisite operating systems, program library, and data base. However, advances in electronic technology, particularly the development of integrated circuits, suggest that it may be desirable, economically and otherwise, to distribute this computational power.

A case in point arises in connection with graphics terminals. Since cathode-ray-tube displays require periodic regeneration, buffer storage at individual consoles is desirable to remove some of the load on the central facility. Where graphic inputs such as a light-pen are involved, there is a similar justification for processing equipment at the console. While it is clear that some computing capability at the console is desirable, the economic trade-offs between central and peripheral processing, and the most efficient way of linking the central machine and its satellites, must be determined experimentally. These questions are closely tied to the modularity and organization of the operating system programs and the file structure and physical distribution of the data.

Research to date indicates in general how such a tightly coupled network of computing systems might be built. What remains to be done is to develop and study a network of computing systems. Such an experimental network, which will initially include computers at Lincoln Laboratory, Systems Development Corporation and Harvard, is currently being established.

C. MAN-MACHINE COMMUNICATION

1. Compilers

Higher order programming languages such as FORTRAN, MAD, LISP, and others, and special "problem-oriented" languages such as STRESS, are useful and indeed necessary, since, with their associated translator/compilers, they provide a powerful set of tools for conventional programming. At the same time, the number and complexity of these languages can lead to a serious strain on system capacity. Compilers are typically large programs, and machine-accessed storage is always limited. In a time-shared environment, transferring such large programs in and out of the central memory is extremely costly in overhead time.

Recent research and the development of a "compiler-compiler" (VITAL) on the TX-2 computer promises to alleviate this problem by means of a single, table-driven compiler. New languages can be defined and added to the system by relatively simple changes in the tables which control the basic translator. The major portion of the software remains unchanged, and in a

time-shared system only the new tables must be switched in and out of central storage. Current research is directed at the improvement of this technique and its extension to graphical languages, which include light-pen and push-button actions as well as conventional character strings.

2. Reckoner

Much of the work of scientists and engineers involves relatively straightforward computations or transformations of data; if work of this kind is to be done expeditiously, it must be unnecessary to write special programs for each task. The recently developed Lincoln Reckoner has demonstrated on TX-2 that it is possible to build a system for automatic procedure execution that provides immediate and flexible access to computational capability without conventional programming. The user simply selects from a library of operations the operation he wishes performed and indicates the data on which he wishes to operate. Results are stored in a form appropriate to further computation if desired, and may also be displayed as graphs or plots on a CRT. The library of operations available to the user may be added to as required; in this sense, the system is open-ended. An improved version of the Lincoln Reckoner system is now under development for the IBM 360/67.

3. Graphics

Graphical techniques are indispensable in dealing with, understanding, or describing many complex processes. Experiments such as SKETCHPAD have indicated some of the potential power in computer graphics. There are a number of difficult technical problems that must be solved, however, before a graphical capability can be made generally available and useful in a time-shared, on-line system. These problems include the development of an appropriate graphical language or languages, efficient data structures for machine representation of graphics, and effective procedures for linking graphical data with nongraphical data and with procedures which they may symbolize or control. Lastly, there is need for further development of terminals, particularly on input devices and techniques. The Data Systems research directed at these problems is supplemented by the ARPA-sponsored GRAPHICS program.

RADIO PHYSICS RESEARCH

A. INTRODUCTION

The Radio Physics Research program utilizes the facilities at the Millstone Hill Field Station for radar studies of satellites and for radar and radiometric studies of the earth's atmosphere, interplanetary space, and lunar and planetary surfaces. These facilities include the 84-foot Millstone tracking radar, the 120-foot high-precision steerable Haystack antenna, and the 220-foot fixed zenith-pointing Ionospheric Research Radar. Another facility utilized in the program is the 28-foot millimeter-wave antenna at the Laboratory in Lexington.

In the new field of radar astronomy, high-power radar techniques are applied to the study of the orbits and surfaces of the moon and neighboring planets in the solar system. Such experiments, combining the economy and shorter development time of earth-based operation, are valuable adjuncts to exploration by manned and unmanned space vehicles. Radar measurements of the composition and behavior of the ionosphere yield information of vital importance to long-distance radio communication. Radio astronomy measurements develop new knowledge of the structure and characteristics of spectral line emission sources and also provide a method for precise determination of antenna surface tolerances. Studies of microwave propagation provide data required for the orderly development of systems for satellite and deep-space communications.

The Radio Physics Research program also includes a modest effort on space surveillance techniques, concerned with the detection and observation of space vehicles. Advanced radar and signal-analysis techniques are developed and exploited to increase the information that can be obtained from radar investigations of natural and man-made objects in space. The Millstone radar, when operating in the space radar mode at 1295 MHz, has demonstrated a satellite tracking capability at ranges as great as 14,000 nautical miles.

The Haystack Microwave Research Facility has recently been equipped with an advanced high-performance radar system designed around a transmitter capable of generating 500,000 watts of power at a frequency of 7840 MHz. Considerable emphasis has been placed upon the use of improved components for

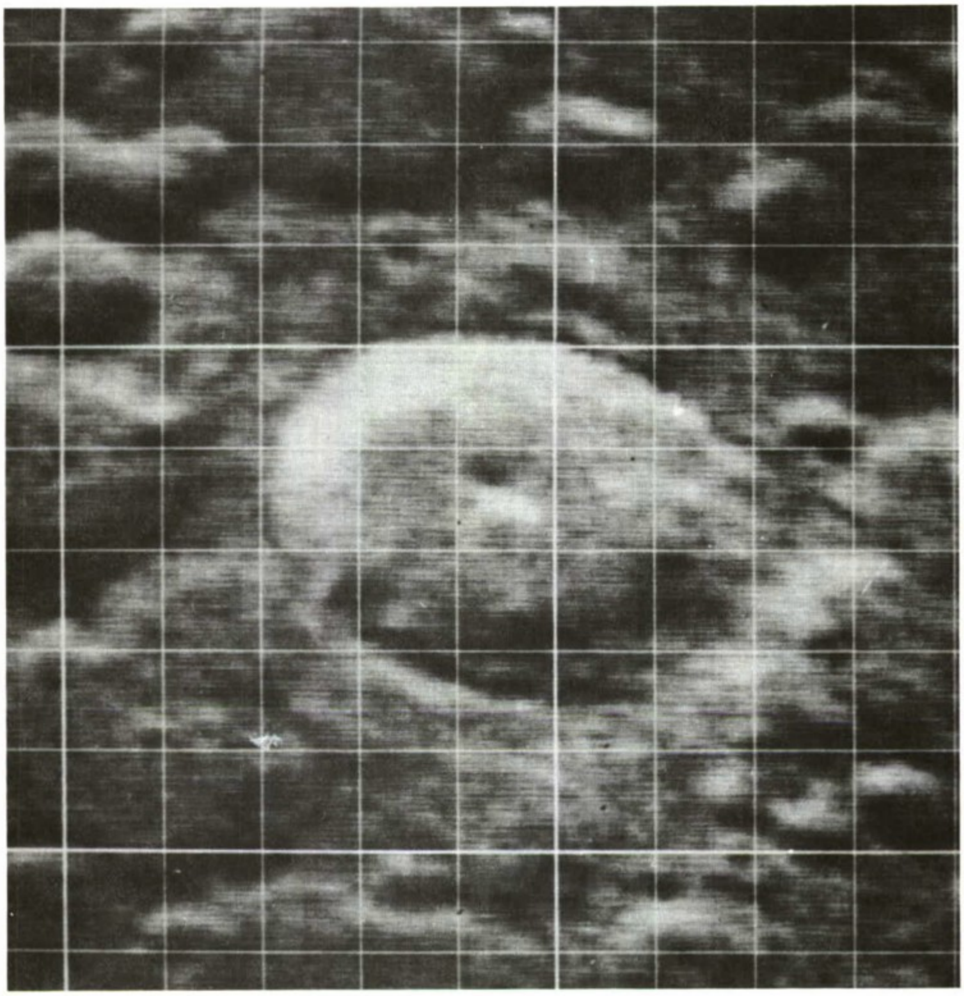
the distribution, monitoring, and control of the very high microwave power densities. While cooled parametric amplifiers provide adequate receiver performance for many applications, certain radio astronomy studies require the extremely low receiver noise available with the 10°K helium-cooled maser recently incorporated into the system. Studies of the Haystack antenna are continuing to establish new limits on the precision in large steerable reflectors. Data transmission, timing, and control circuits provide a comprehensive Intersite Coupling System between Millstone and Haystack. This permits the establishment of flexible system configurations, thus affording more efficient use of subsystems at both locations as well as two-antenna interferometric system arrangements.

Work directed toward enhanced receiver and transmitter capabilities at millimeter wavelengths continues. The existing 28-foot-diameter antenna at the Laboratory is being equipped with a one-kilowatt average power transmitter, operating at 8 millimeters, and an improved receiver. This new capability should provide high-angular-resolution millimeter-wave radar information about the lunar surface, complementing that obtained at L- and X-bands by Millstone and Haystack. The wavelength of 8 millimeters also offers interesting possibilities for studies of atmospheric effects.

B. RADAR AND RADIO ASTRONOMY

1. Atmospheric Studies

A systematic program of measurements of the electron density and kinetic temperature of free electrons and ions in the earth's ionosphere, including diurnal and seasonal variations and those associated with unusual solar events, was begun in 1963, during the time of the quiet sun. Both the Millstone steerable 1295 MHz radar and the 440 MHz zenith-pointing ionospheric radar have been used to observe Thomson scattering, primarily in the F-region at altitudes from 200 km to about 700 km. Improved range resolution is being provided to facilitate measurements down into the E-region, where changes in chemical composition are of particular interest. These measurements, in combination with measurements by other organizations, from similar radars



High-resolution 3.8 centimeter range-Doppler radar reflectivity map of the lunar crater Tycho made at the Haystack Microwave Research Facility. Grid lines spacing is approximately 17 kilometers.

at different geomagnetic latitudes and from satellites and sounding rockets, are contributing to an improved understanding of the thermal and chemical properties of the upper atmosphere, within and through which many important sensor and communications systems must work. It is intended that this work continue until about 1969, through the current upswing in the solar cycle, to encompass all degrees of solar activity.

2. Lunar Studies

Radiometric and radar studies of the surfaces and orbits of the moon and planets are of immediate interest to the nation's space program. Measurements of the depolarization and scattering matrix and fine-grained mapping of reflectivity are substantially augmenting our knowledge of the nature of the lunar surface. The results are reported to NASA as an aid in the choice of Apollo landing sites. Some of these techniques will be applied to the surface of Venus during the next inferior conjunction in August 1967.

Highlights of this program include:

(a) Precise measurement of total radar cross section of the moon at several frequencies. The Lincoln Calibration Sphere ($\sigma = 1.0\ m^2$) in its 1500-nautical-mile circular orbit is employed as a calibration standard.

(b) Determination of the average reflectivity and depolarizing characteristics as functions of angle of incidence and of polarization relative to plane of incidence.

(c) Refinement of the delay-doppler mapping technique to permit a reflectivity-mapping resolution at X-band of 1 – 2 km, comparable to that of telescope photographs.

(d) Development of a new method of mapping at L-band that will permit detailed polarimetric studies of small areas of the surface.

(e) Theoretical consideration of all available data, aimed at an improved model for the lunar surface. Studies will yield values for the dielectric constant (with implications as to bulk density), mean surface slopes, densities of boulders on the surface, etc.

3. Planetary Studies

The precise ranging capability of the new Haystack planetary radar system permits a measurement accuracy of better than 10 microseconds in 1700 seconds of delay. An application of fundamental scientific importance is a new test of Einstein's General Theory of Relativity, a test potentially more precise than any heretofore. This test, proposed by I. I. Shapiro of Lincoln Laboratory, requires a careful comparison of accurate planetary echo delay measurements, over a complete synodic orbital period, with predictions based upon both classical and relativistic theories. The planets Mercury and Venus are particularly suitable targets, since the Haystack facility has the sensitivity to observe them throughout their orbits.

These measurements permit not only a search for the predicted relativistic delay in the radar signal as it traverses the intense solar gravitational field, but also a verification of the predicted advance in the line of apsides of Mercury's orbit.

In addition to the high-power component development required by this experiment, signal processing techniques have had to be increased in efficiency. A very effective new technique developed at the Laboratory provides for developing the cross-correlation function between a delay-doppler map prepared from the actual radar data and a corresponding map computed from predicted planetary motions and scattering characteristics. The method makes efficient use of the returned signal power from a major portion of the visible planetary surface in determining the delay of the returned signal.

Although it will be some time before there is sufficient radar performance to make possible radar maps of the planetary surfaces in as fine detail

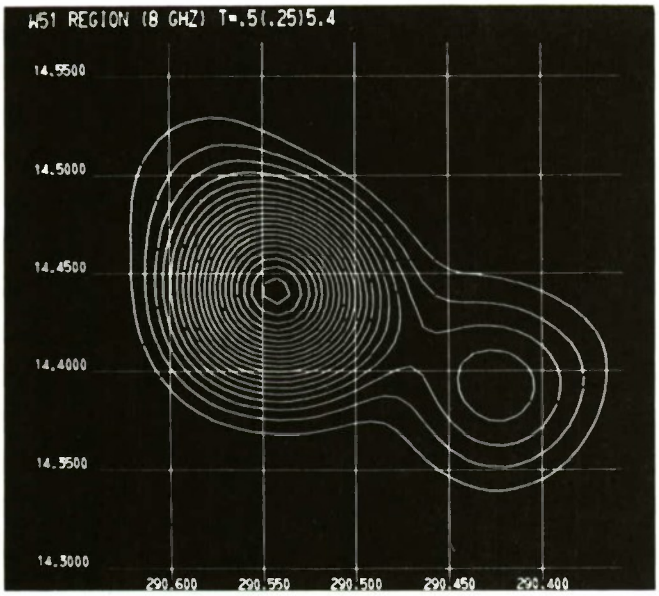
as those now made of the moon, measurements of scattering laws and polarization effects and multi-frequency reflectivity measurements can be expected to lead to some conclusions concerning the major surface features and atmosphere of Venus.

4. Radio Astronomy

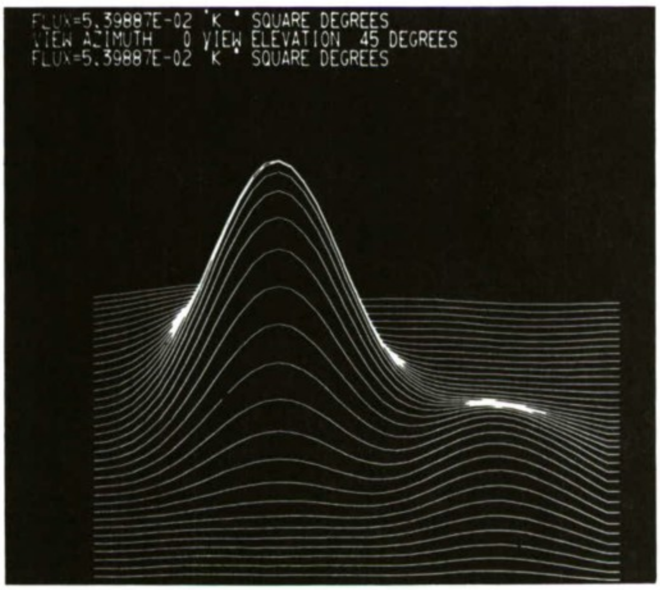
Since the discovery of the OH absorption line at the Millstone Radar several years ago, the Millstone Hill Field Station has exploited its unusual polarization flexibility and signal processing capability to explore new OH emission features. Near-real-time spectral line processing and display, making use of the Weinreb correlator and computer combination, is a powerful new technique, first employed at the Station. A spectral-line interferometer linking the Millstone and Haystack antennas revealed the very small angular size of certain of these emission features, and an extension of the interferometer to include Millstone and the Harvard Observatory Agassiz Station subsequently revealed that the size of these same sources is yet another order of magnitude smaller. These observations have prompted theoretical studies by Lincoln physicists that offer an explanation of the generating mechanism for these unusual emissions in terms of an interstellar OH maser pumped by ultraviolet radiation from a nearby hot star.

Another area of particular interest is the study of spectral lines of excited hydrogen at frequencies ranging from L-band to X-band. Other work includes radiometric mapping of discrete radio sources and of the galactic center. Sophisticated computer utilization has permitted unusually detailed three-dimensional plotting and displays of intensity variations over regions of interest in the sky. Use of the Field Station facilities in experiments conducted jointly by Lincoln staff members and faculty and students from M.I.T. and Harvard ensures a highly effective utilization of the available facilities and operating time.

In addition to the general impetus given by radio astronomy to the advanced development of receiver and signal processing techniques, this work has yielded direct and highly accurate methods of measuring the efficiency, surface deviations, and pointing accuracy of large antennas using known celestial sources



Contour map (above) and corresponding ruled-surface display (below) of thermal emission from galactic radio source W51 illustrate an advanced application of digital computing techniques to radio astronomy measurements at Haystack. In generating these maps, antenna pointing, system calibration, and data recording, analysis, and display are all computer-controlled, greatly increasing the efficiency with which the system can be used for this type of measurement.



of radiation. These methods are applicable to any large radar or radiometric installation, military or scientific.

C. APPLIED RESEARCH

1. Space Communications

The interaction of the disturbed troposphere with the short centimeter wavelengths is of increasing interest in satellite communications and, in particular, to the Laboratory's Space Communications program. These wavelengths are known to be significantly attenuated in rain and heavy clouds, and there is a radiometric rise in receiving system noise temperature which accompanies this attenuation. This noise is becoming more important as more sensitive amplifiers are developed in this wavelength region. For this reason, a study of both attenuation (using existing communication satellites) and the associated emission noise is planned using the Haystack Facility. Ancillary information on distribution and intensity of rain showers is required for meaningful interpretation of the path loss and noise measurements. This information is provided by the Millstone L-band radar system with a modification to permit high resolution. An S-band scanning radar has been installed to detect weather conditions suitable for the measurements and to furnish data for directing the Millstone and Haystack antennas.

2. Space Surveillance

As perhaps the longest-range tracking radar available today, the Millstone L-band system is used on a scheduled basis and in emergencies as a sensor for the Air Force Space Defense Center and as a test bed for various improved satellite observing techniques. Its tracking capability and target illuminating power are also employed in the MITRE-Millstone three-station developmental radar interferometer system, which also includes 30-foot-diameter receiving antennas at MITRE-Bedford and on Boston Hill in North Andover and data processing facilities in Bedford. This interferometer is based on a 2-station system proved feasible at Millstone in 1959.

Computer-smoothed pointing data from satellite tracks can also be used to point the Haystack radar and experimental optical or infrared sensors installed on a tower near the Millstone Radar.

Conversion in 1963 of the Millstone Radar from its original UHF configuration to its present L-band monopulse arrangement more than doubled its tracking range to the present value of 5000 nautical miles on a 1-square-meter target. Computer programs are being developed for improvement of satellite orbit parameters during real-time observation so that the computer can assist the radar in maintaining track during target "fades." Signal detection techniques developed for radar astronomy will be used to extend tracking ranges on weak satellite targets.

COMMUNICATIONS RESEARCH

A. INTRODUCTION

The General Research program in Communications supplements the major effort of the Laboratory in Space Communications by providing support for exploratory research in promising and potentially important areas which are not yet immediately applicable to military space communications. The objective of this research is to investigate advanced techniques for the efficient coding and transmission of information over channels which are subject to natural or man-made disturbances.

B. RESEARCH TOPICS

1. Modulation Techniques

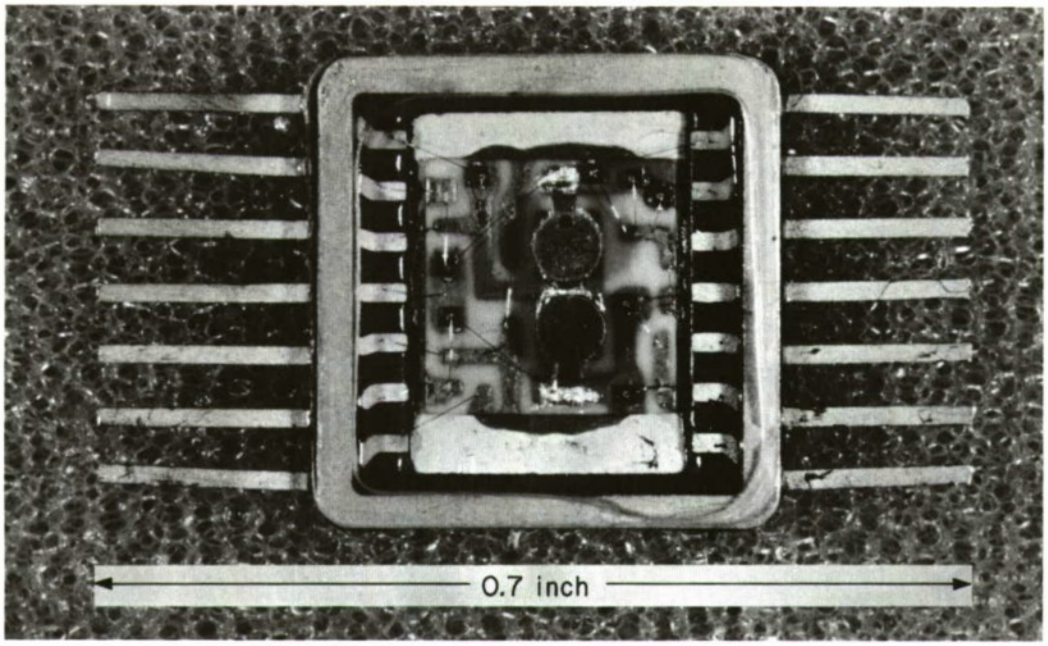
Techniques are under investigation for adaptive high-speed digital transmission over time-varying channels, such as telephone lines and high-frequency radio circuits. These techniques will be tested in a high-speed digital transmission system designed for switched telephone lines. Theoretical and simulation studies relating to HF and UHF tropospheric radio applications are also being carried out.

2. Vocoders

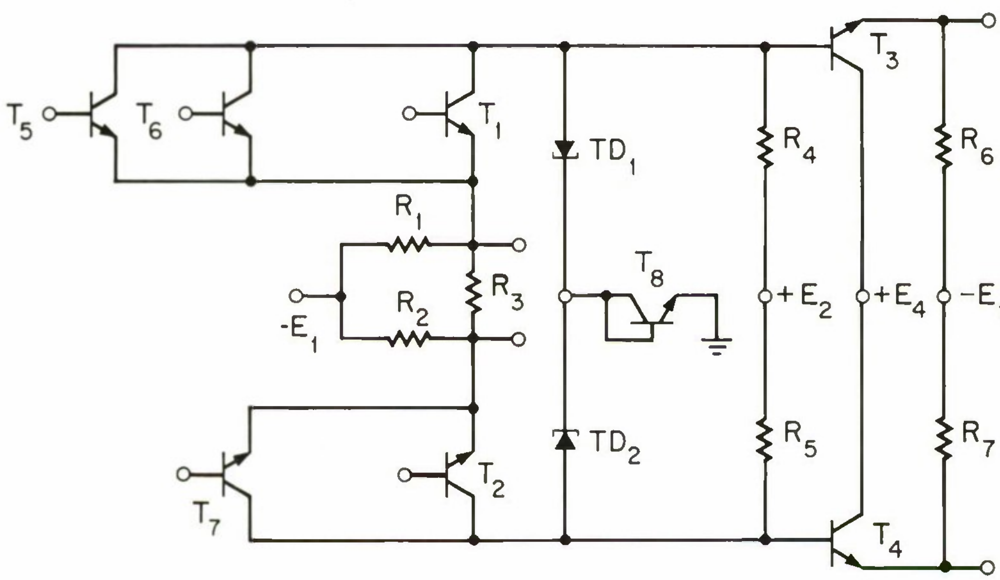
New methods of digital speech processing, including combined formant tracking and channel vocoders and limited vocabulary word recognizers, are being developed and tested. The effect of context on speech recognition is being investigated. Theoretical studies of the permissible distortion in digital speech processing systems, in terms of the hearing process in humans, are under way.

3. Coding

Recently proposed modulation, coding, and source encoding information processing techniques require very-high-speed digital processors. A small



Transistor-gated universal logic function module used in very-high-speed arithmetic processor at 100 MHz clockrate. These modules, each of which contains two tunnel diodes and eight transistors in the circuit configuration shown below, will be mounted on newly-developed multi-layered strip-line printed circuit boards to reduce the stage delay to less than 1 nanosecond per module.



general-purpose computer is being equipped with an experimental very-high-speed arithmetic processor to test the possibility of using general-purpose computing machines to carry out various communication operations and to aid in the simulation of complex speech and communication systems in real-time or close to real-time.

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13. ABSTRACT

This report is a summary of Lincoln Laboratory's current program of General Research which is a source of new technology for projects of Lincoln Laboratory, the Department of Defense, and other federal agencies. The report covers research in Solid State, Data Systems, Radio Physics, and Communications.

14. KEY WORDS

data systems	control research	microwave equipment
digital computers	radio physics	mechanical and structural engineering
computer components	space surveillance	solid state physics
psychology	radar	